Verifying ontological knowledge through meta-analysis: Study cases of Pain and Consciousness

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Study cases of Pain and Consciousness

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1 INTRODUCTION

A main goal in current neuroscience is understanding of how different cognitive functions originate in the brain. To achieve this, several projects [2, 6, 4] developed in the last decade sparked large heterogeneous databases. But at present, there is no unifying framework to represent theories.

Progress has been made through meta-analysis but some limitations remain to be addressed. With Neurosynth [7], for example, we can't analyse whether, in the literature, terms dubbed as synonyms are really used in an exchangeable manner across articles. Furthermore, the type of queries that can be used can only be based on propositional logic.

In this work, we address these issues by introducing NeuroLang, a probabilistic language based on Datalog$^{+/-}$[1] that was intended as a first-order logic-based tool. We will use NeuroLang's ability to combine structured knowledge and its power to perform queries based on first-order logic to perform an analysis of the relationship between ontological properties.

We will show how, by analysing the changes in the statistical power of meta-analysis data, we can confirm the hierarchization of terms in ontologies.

2 METHODS

To analyze the hierarchical knowledge within an ontology we will make use of the NeuroSynth [7] meta-analisys database. It's composed of 3228 terms related to the activations of 14371 different studies. This data allows us to relate terms from the ontology and activations in the brain. If several words represent the same concept, then using studies mentioning either word should provide similar results, hence increasing the statistical power of meta-analyses. We will analyze the statistical power of different term comparing the variance in the top 5% of the most relevant activations.

We will use the CogAt [5] ontology to analyze the terms *'consciousness'* and *'awareness'* with the disjunction of them (*'consciousness or awareness'*, called synonyms). Then, we will perform the same procedure using the IOBC ontology [3], to analyze combinations of the terms *'noxious'*, *'pain'*, *'nocinceptive'* and their disjunctions.

To calculate the statistically relevant activations we will use the NeuroLang software package. Using the k-fold technique we will separate the documents into 10 folds, obtain $P(voxel|term)$ for each term and then calculate mean and variance of each result.

3 RESULTS

3.1 Synonyms

We analyzed some of the terms that define relationships using the *skos:altLabel* property. First, let's look at CogAt's terms. As we can see Figures 1(d) and 1(e) show how most of the voxels have negative values in the subtraction. This means that the result based on synonyms has a higher statistical power and the studies represented by them refer to the same phenomenon. These results are quantitatively confirmed in Table 1, which shows that, on average, 80% of the voxels have a lower standard deviation in the synonym.

The same result can be observed using the IOBC ontology[3] with the terms '*noxious*', '*nocinceptive*' and their disjunction. In the next step we will see how an entity related to these two doesn't behave in the same way when it's no longer considered a synonym.

3.2 Related terms

Now let's expand the previous IOBC terms by adding *pain*, related to the others entities through the *skos:related* property. In Figure 2(h) we can observe a large number of voxels where the subtraction is greater than zero. We can confirm this phenomenon by looking at Table 3. As a result, the decision to establish the term '*pain*' as a related term in the IOBC[3] ontology, is in agreement with the neuroscientific knowledge.

	# voxels with std > 0	# voxels with std < 0	total
Synonyms - Consciousness	1151 (21.5%)	**4200 (78.5%)**	5351
Synonyms - Awareness	225 (14.5%)	**1328 (85.5%)**	1553

Table 1. Value of the voxels resulting from subtracting the standard deviation of the activations of each individual term from the logical disjunction of both terms after filtering and obtaining the top 5% of the most relevant activations. Values greater than zero imply a lower std in the voxels of the isolated term, while values less than zero imply a lower std in the disjunction of the terms. On average, more than 80% of voxels present a lower std when using the disjunction of both terms ('*Consciousness*' and '*Awareness*'), supporting the idea that they are treated as synonyms by the neuroscientific community and validating the structure of the ontology.

	# voxels with std > 0	# voxels with std < 0	total
Synonyms - Noxious	236 (9.76%)	**2182 (90.24%)**	2418
Synonyms - Nocinceptive	44 (1.49%)	**2917 (98.51%)**	2961

Table 2. Value of the voxels resulting from subtracting the standard deviation of the activations of each individual term from the logical disjunction of both terms after filtering and obtaining the top 5% of the most relevant activations. Values greater than zero imply a lower std in the voxels of the isolated term, while values less than zero imply a lower std in the disjunction of the terms. On average, more than 80% of voxels present a lower std when using the disjunction of both terms ('*noxious*' and '*nocinceptive*'), supporting the idea that they are treated as synonyms by the neuroscientific community and validating the structure of the ontology.

	# voxels with std > 0	# voxels with std < 0	total
Synonyms - Pain	**10199 (66.03%)**	5248 (33.97%)	15447

Table 3. Value of the voxels resulting from subtracting the standard deviation of the activations of the term '*pain*' from the logical disjunction of the terms '*pain*', '*noxious*' and '*nocinceptive*' after filtering and obtaining the top 5% of the most relevant activations. Values greater than zero imply a lower std in the voxels of the isolated term, while values less than zero imply a lower std in the disjunction of the terms. In this case, more than 65% of voxels present a higher std when using the disjunction of the three terms ('*Pain*', '*Noxious*' and '*Nocinceptive*'), supporting the ontological structure, which does not consider '*pain*' a synonym of the rest of the terms.

4 CONCLUSIONS

We show how, using the meta-analytic knowledge of the neuroscientific community, we can confirm some of the relations established in the ontologies by analyzing their statistical power. Replicating this experiment in more databases, such as NeuroQuery, should be the next step. In spite of some limitations, we consider that this is an interesting step on the path of confirming ontological relations in a quantitative way.

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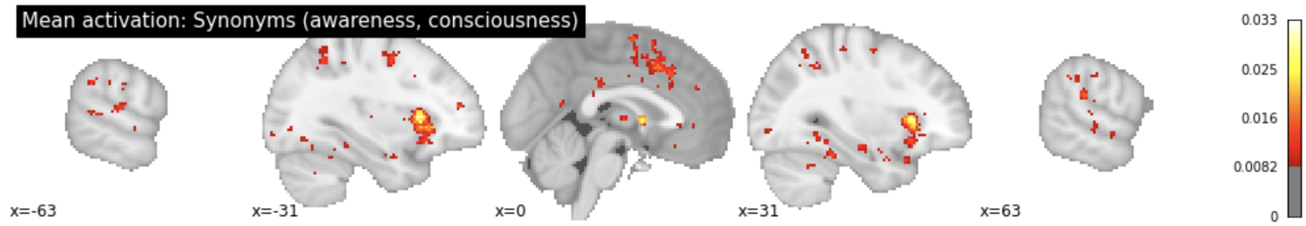
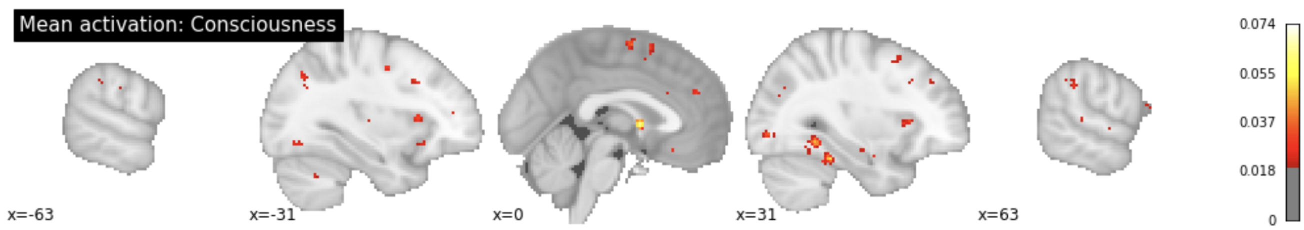
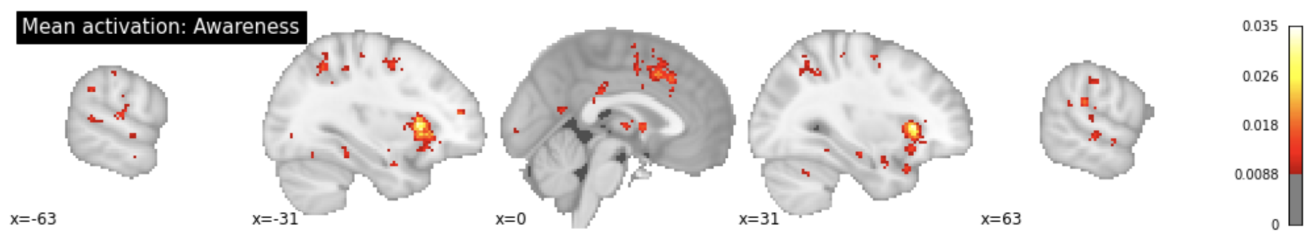


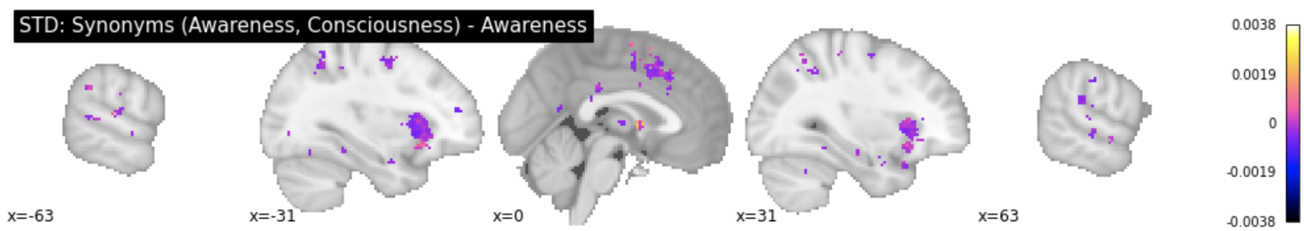
(a) Terms: Awareness, Consciousness



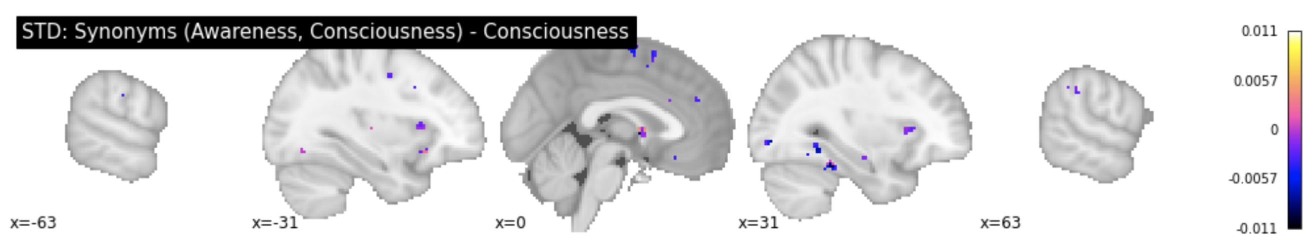
(b) Terms: Consciousness



(c) Terms: Awareness

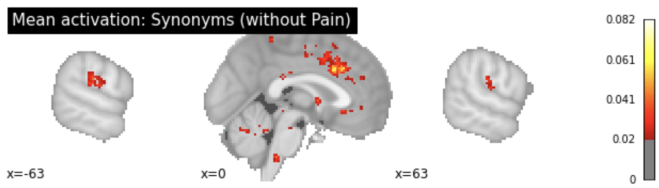


(d) Subtraction between the STDs of figures (a) and (b)

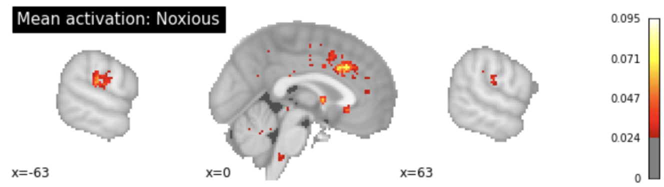


(e) Subtraction between the STDs of figures (a) and (c)

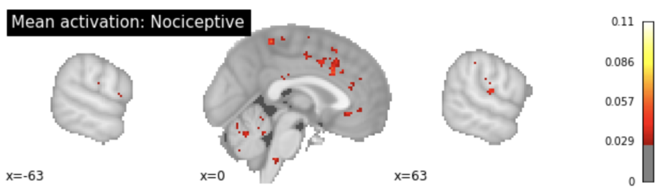
Figure 1. Figure (a), (b) and (c): Comparison between the mean activations obtained by the disjunction of the terms obtained as alternative names of '*consciousness*' in the CogAt[5] ontology (both '*consciousness*', '*awareness*') and the terms '*consciousness*' and '*awareness*'. Figure (d) shows the result of subtracting the standard deviation of figures (a) and (b) in such a way that values less than zero indicate that the variance in figure (a) is lower than in figure (b) and higher in the case of values greater than zero. Same case in figure (e) for the subtraction between the STDs in figures (a) and (c).



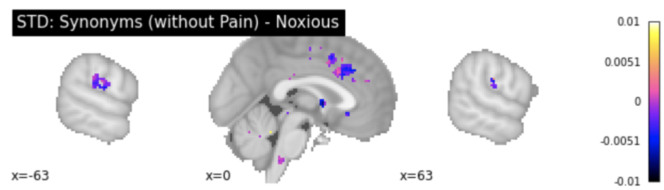
(a) Terms: Noxious, Nociceptive



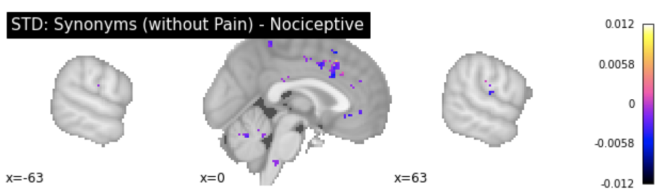
(b) Terms: Noxious



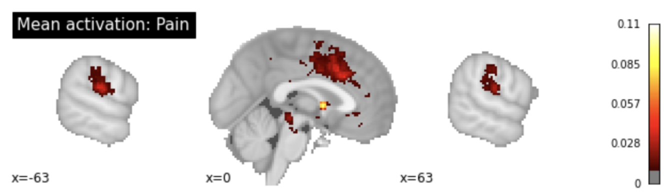
(c) Terms: Nociceptive



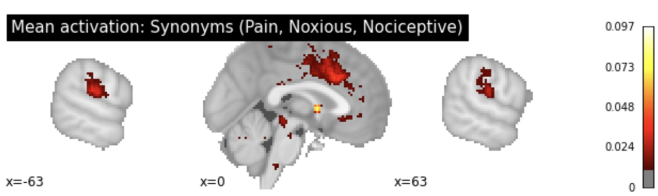
(d) Subtraction between the STDs of figures (a) and (b)



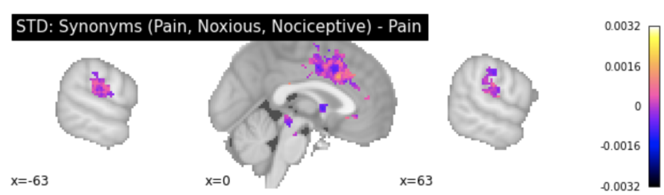
(e) Subtraction between the STDs of figures (a) and (c)



(f) Terms: Pain



(g) Terms: Pain, Noxious, Nociceptive



(h) Subtraction between the STDs of figures (a) and (b)

Figure 2. Figure (a), (b) and (c): Comparison between the mean activations obtained by the disjunction of the terms obtained as alternative names of 'noxious' in the IOBC ontology (both '*noxious*' and '*nociceptive*') and the terms '*noxious*' and '*nociceptive*' as single terms. Figure (d) shows the result of subtracting the standard deviation of figures (a) and (b) in such a way that values less than zero indicate that the variance in figure (a) is lower than in figure (b) and higher in the case of values greater than zero. Same case in figure (e) for the subtraction between the STDs in figures (a) and (c). Figure (f) and (g): Comparison between the mean activations obtained by the term '*pain*' and the disjunction of the terms obtained as related entities in the IOBC ontology ('*pain*', '*noxious*', '*nocinceptive*'). Figure (h) shows the result of subtracting the standard deviation of figures (f) and (g) in such a way that values less than zero indicate that the variance in figure (f) is lower than in figure (g) and higher in the case of values greater than zero.

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